

EVALUATION OF n + 206Pb CROSS SECTIONS FOR THE ENERGY
RANGE 1.0E-11 to 150 MeV

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This evaluation provides a complete representation of the nuclear data needed for transport, damage, heating, radioactivity, and shielding applications over the incident neutron energy range from 1.0E-11 to 150 MeV. The discussion here is divided into the region below and above 20 MeV.

INCIDENT NEUTRON ENERGIES < 20 MeV

Below 20 MeV the evaluation is based completely on the ENDF/B-VI.0 (Release 0) evaluation by Fu91. The following modifications were made to the ENDF/B-VI.0 evaluation:

1. The covariance files (MF=33) were removed from the file.
2. The derived MF=3 files for MT=203,205,207 were removed.

INCIDENT NEUTRON ENERGIES > 20 MeV

The evaluation above 20 MeV utilizes MF=6, MT=5 to represent all reaction data. Production cross sections and emission spectra are given for neutrons, protons, deuterons, tritons, alpha particles, gamma rays, and all residual nuclides produced ($A>5$) in the reaction chains. To summarize, the ENDF sections with non-zero data above $E_n = 20$ MeV are:

- MF=3 MT= 1 Total Cross Section
MT= 2 Elastic Scattering Cross Section
MT= 3 Nonelastic Cross Section
MT= 5 Sum of Binary (n,n') and (n,x) Reactions
- MF=4 MT= 2 Elastic Angular Distributions
- MF=6 MT= 5 Production Cross Sections and Energy-Angle Distributions for Emission Neutrons, Protons, Deuterons, and Alphas; and Angle-Integrated Spectra for Gamma Rays and Residual Nuclei That Are Stable Against Particle Emission

The evaluation is based on nuclear model calculations that have been benchmarked to experimental data, especially for n + Pb and p + Pb208 reactions (Ch96a). We use the GNASH code system (Yo92), which utilizes Hauser-Feshbach statistical, preequilibrium and direct-reaction theories. Coupled-channel and spherical optical model calculations are used to obtain particle transmission coefficients for the Hauser-Feshbach calculations, as well as for the elastic neutron angular distributions.

Cross sections and spectra for producing individual residual nuclei are included for reactions that exceed a cross section of approximately 1 nb at any energy. The energy-angle-correlations for all outgoing particles are based on Kalbach systematics (Ka88).

A model was developed to calculate the energy distributions of

all recoil nuclei in the GNASH calculations (Ch96b). The recoil energy distributions are represented in the laboratory system in MT=5, MF=6, and are given as isotropic in the lab system. Note that all other data in MT=5, MF=6 are given in the center-of-mass system. This method of representation requires a modification of the original ENDF-6 format.

Preequilibrium corrections were performed in the course of the GNASH calculations using the exciton model of Kalbach (Ka77, Ka85), validated by comparison with calculations using Feshbach, Kerman, Koonin (FKK) theory [Ch93]. Discrete level data from nuclear data sheets were matched to continuum level densities using the formulation of Ignatyuk (Ig75) and pairing and shell parameters from the Cook (Co67) analysis. Neutron and charged-particle transmission coefficients were obtained from the optical potentials, as discussed below. Gamma-ray transmission coefficients were calculated using the Kopecky-Uhl model (Ko90).

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82206 = TARGET 1000Z+A (if A=0 then elemental)

1 = PROJECTILE 1000Z+A

Nonelastic, elastic, and Production cross sections for A<5 projectiles in barns:

Energy	nonelas	elastic	neutron	proton	deuteron	triton	helium3	alpha	gamma
2.000E+01	2.604E+00	3.240E+00	5.996E+00	2.176E-02	2.810E-03	2.930E-04	0.000E+00	1.038E-03	9.070E+00
2.200E+01	2.591E+00	3.214E+00	6.595E+00	3.223E-02	4.480E-03	5.584E-04	0.000E+00	1.482E-03	9.734E+00
2.400E+01	2.586E+00	3.106E+00	6.847E+00	4.560E-02	6.275E-03	8.643E-04	0.000E+00	1.943E-03	1.108E+01
2.600E+01	2.594E+00	2.937E+00	6.971E+00	6.292E-02	8.185E-03	1.178E-03	0.000E+00	2.408E-03	1.239E+01
2.800E+01	2.577E+00	2.760E+00	7.142E+00	8.395E-02	1.015E-02	1.474E-03	0.000E+00	2.849E-03	1.248E+01
3.000E+01	2.558E+00	2.569E+00	7.483E+00	1.088E-01	1.221E-02	1.758E-03	0.000E+00	3.281E-03	1.137E+01
3.500E+01	2.541E+00	2.109E+00	8.062E+00	1.867E-01	1.732E-02	2.301E-03	0.000E+00	4.297E-03	1.039E+01
4.000E+01	2.502E+00	1.858E+00	8.274E+00	2.775E-01	2.203E-02	2.654E-03	0.000E+00	5.151E-03	1.099E+01
4.500E+01	2.433E+00	1.821E+00	8.597E+00	3.423E-01	2.475E-02	2.903E-03	0.000E+00	6.069E-03	1.155E+01
5.000E+01	2.383E+00	1.907E+00	8.836E+00	4.027E-01	2.692E-02	3.087E-03	0.000E+00	7.086E-03	1.169E+01
5.500E+01	2.323E+00	2.074E+00	9.079E+00	4.553E-01	2.852E-02	3.233E-03	0.000E+00	8.134E-03	1.114E+01
6.000E+01	2.274E+00	2.208E+00	9.262E+00	5.050E-01	2.990E-02	3.366E-03	0.000E+00	9.284E-03	1.109E+01
6.500E+01	2.200E+00	2.402E+00	9.342E+00	5.440E-01	3.080E-02	3.478E-03	0.000E+00	1.040E-02	1.113E+01
7.000E+01	2.125E+00	2.573E+00	9.254E+00	5.768E-01	3.171E-02	3.609E-03	0.000E+00	1.159E-02	9.793E+00
7.500E+01	2.050E+00	2.700E+00	9.224E+00	6.056E-01	3.233E-02	3.745E-03	0.000E+00	1.271E-02	9.459E+00
8.000E+01	1.976E+00	2.830E+00	9.174E+00	6.293E-01	3.266E-02	3.876E-03	0.000E+00	1.391E-02	8.866E+00
8.500E+01	1.923E+00	2.883E+00	9.198E+00	6.549E-01	3.299E-02	4.036E-03	0.000E+00	1.530E-02	8.501E+00
9.000E+01	1.893E+00	2.853E+00	9.319E+00	6.848E-01	3.356E-02	4.269E-03	0.000E+00	1.704E-02	8.429E+00
9.500E+01	1.855E+00	2.808E+00	9.378E+00	7.083E-01	3.385E-02	4.508E-03	0.000E+00	1.965E-02	8.487E+00
1.000E+02	1.822E+00	2.768E+00	9.449E+00	7.304E-01	3.419E-02	4.792E-03	0.000E+00	2.631E-02	8.240E+00
1.100E+02	1.780E+00	2.594E+00	9.663E+00	7.772E-01	3.459E-02	5.489E-03	0.000E+00	5.493E-02	8.162E+00
1.200E+02	1.742E+00	2.416E+00	9.861E+00	8.167E-01	3.441E-02	6.337E-03	0.000E+00	5.002E-02	7.793E+00
1.300E+02	1.704E+00	2.249E+00	1.001E+01	8.484E-01	3.423E-02	7.334E-03	0.000E+00	5.944E-02	7.638E+00
1.400E+02	1.666E+00	2.072E+00	1.012E+01	8.744E-01	3.386E-02	8.438E-03	0.000E+00	7.177E-02	7.529E+00
1.500E+02	1.630E+00	1.928E+00	1.028E+01	8.918E-01	3.339E-02	9.921E-03	0.000E+00	8.013E-02	7.556E+00

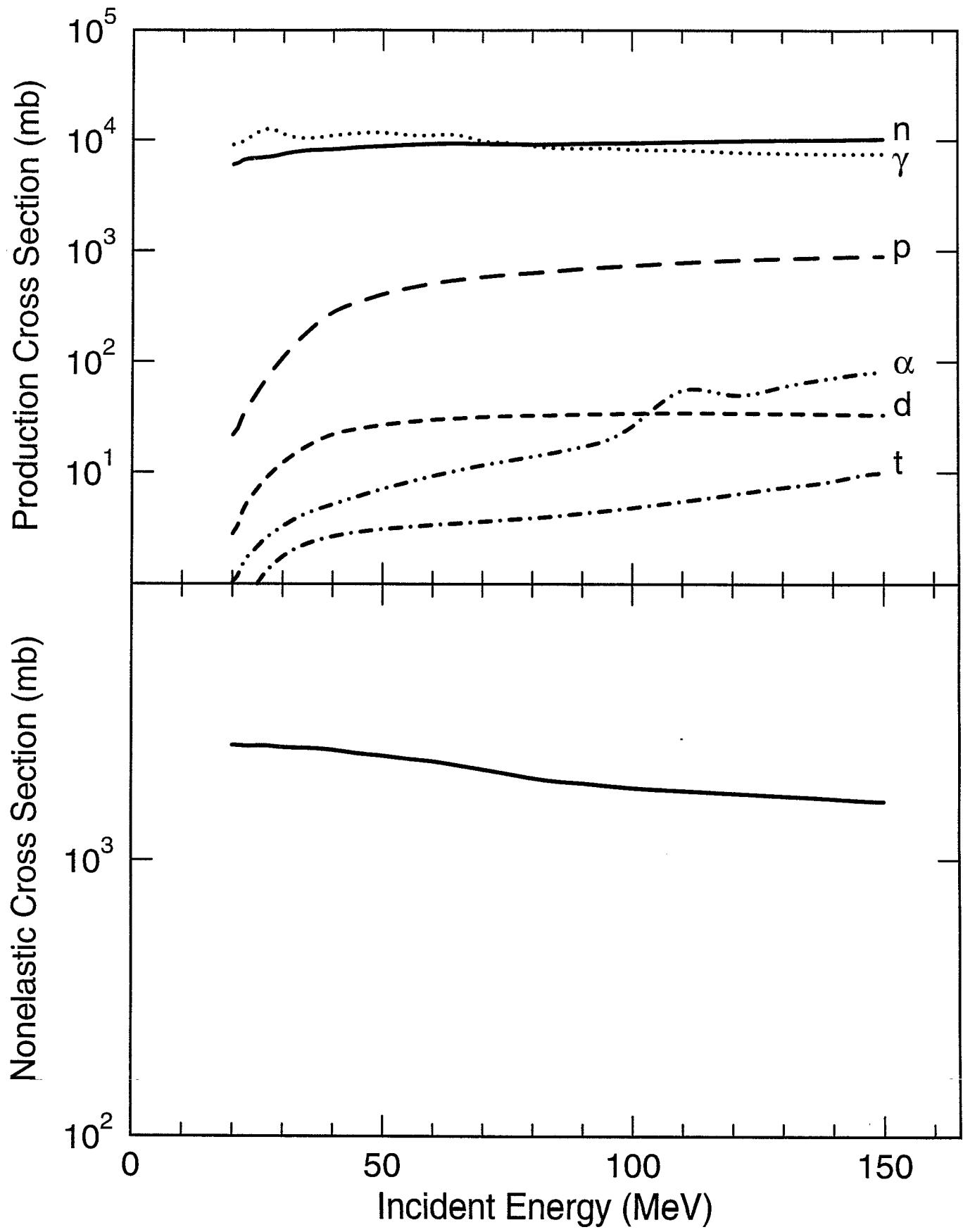
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1 = PROJECTILE 1000Z+A

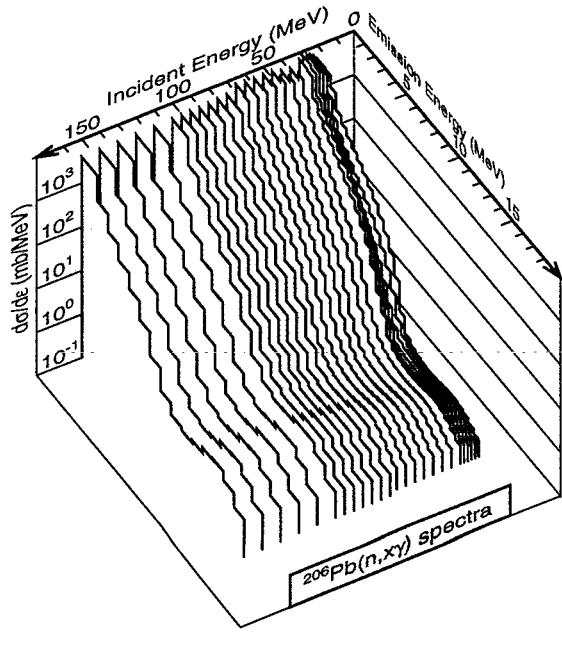
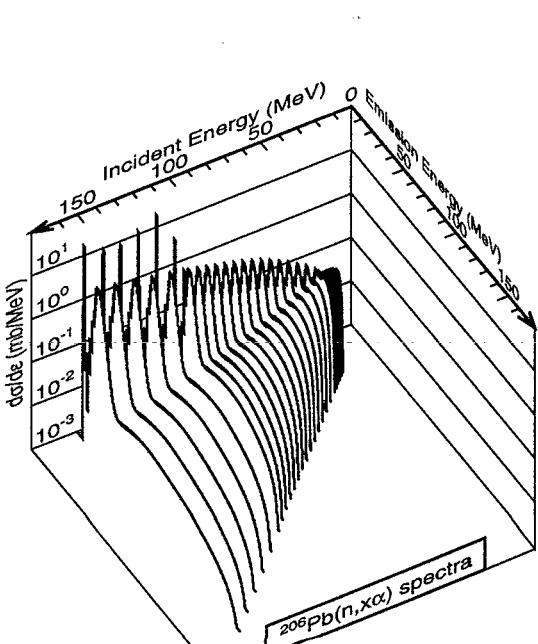
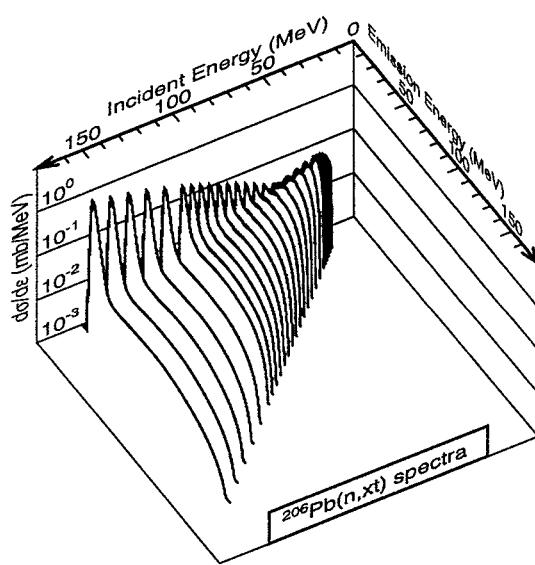
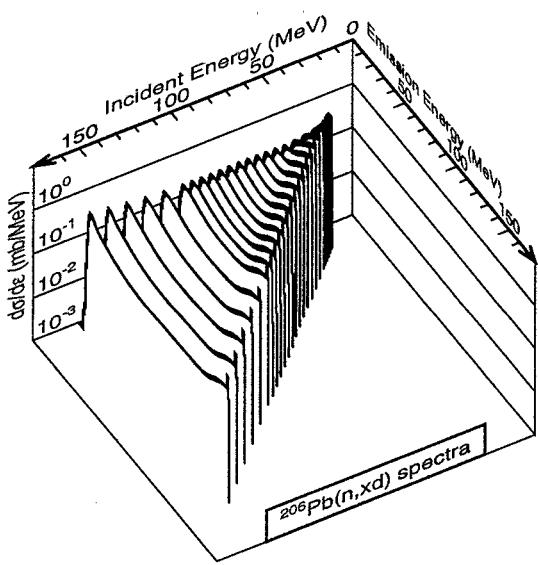
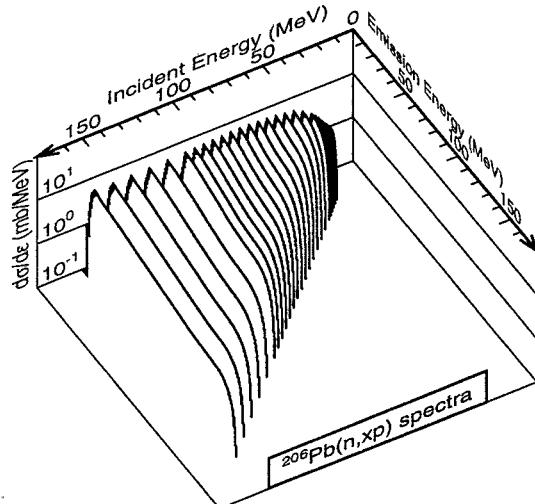
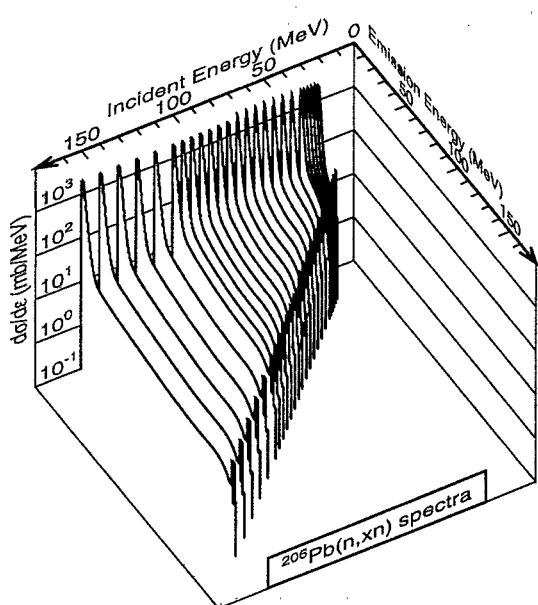
Kerma coefficients in units of f.Gy.m^2:

Energy	proton	deuteron	triton	helium3	alpha	non-rec	elas-rec	TOTAL
2.000E+01	1.389E-02	1.664E-03	1.511E-04	0.000E+00	1.014E-03	1.423E-02	2.732E-03	3.368E-02
2.200E+01	2.191E-02	2.930E-03	3.167E-04	0.000E+00	1.510E-03	1.559E-02	2.295E-03	4.455E-02
2.400E+01	3.273E-02	4.488E-03	5.324E-04	0.000E+00	2.053E-03	1.693E-02	2.305E-03	5.903E-02
2.600E+01	4.740E-02	6.341E-03	7.814E-04	0.000E+00	2.625E-03	1.822E-02	2.331E-03	7.770E-02
2.800E+01	6.623E-02	8.450E-03	1.046E-03	0.000E+00	3.193E-03	1.931E-02	2.368E-03	1.006E-01
3.000E+01	8.977E-02	1.087E-02	1.326E-03	0.000E+00	3.771E-03	2.035E-02	2.393E-03	1.285E-01
3.500E+01	1.717E-01	1.790E-02	1.976E-03	0.000E+00	5.212E-03	2.287E-02	2.361E-03	2.220E-01
4.000E+01	2.826E-01	2.602E-02	2.537E-03	0.000E+00	6.534E-03	2.495E-02	2.301E-03	3.449E-01
4.500E+01	3.807E-01	3.284E-02	3.050E-03	0.000E+00	7.907E-03	2.655E-02	2.538E-03	4.535E-01
5.000E+01	4.832E-01	3.946E-02	3.514E-03	0.000E+00	9.382E-03	2.809E-02	2.723E-03	5.664E-01
5.500E+01	5.840E-01	4.555E-02	3.937E-03	0.000E+00	1.087E-02	2.926E-02	2.850E-03	6.765E-01
6.000E+01	6.873E-01	5.152E-02	4.330E-03	0.000E+00	1.245E-02	3.029E-02	2.828E-03	7.887E-01
6.500E+01	7.814E-01	5.681E-02	4.676E-03	0.000E+00	1.395E-02	3.077E-02	2.818E-03	8.904E-01
7.000E+01	8.715E-01	6.243E-02	5.025E-03	0.000E+00	1.546E-02	3.119E-02	2.617E-03	9.882E-01
7.500E+01	9.599E-01	6.750E-02	5.361E-03	0.000E+00	1.687E-02	3.121E-02	2.406E-03	1.083E+00
8.000E+01	1.044E+00	7.197E-02	5.644E-03	0.000E+00	1.827E-02	3.105E-02	2.257E-03	1.174E+00
8.500E+01	1.136E+00	7.645E-02	5.916E-03	0.000E+00	1.986E-02	3.114E-02	2.096E-03	1.271E+00
9.000E+01	1.239E+00	8.143E-02	6.239E-03	0.000E+00	2.178E-02	3.144E-02	1.922E-03	1.382E+00
9.500E+01	1.335E+00	8.577E-02	6.526E-03	0.000E+00	2.389E-02	3.156E-02	1.776E-03	1.485E+00
1.000E+02	1.432E+00	9.031E-02	6.822E-03	0.000E+00	2.723E-02	3.163E-02	1.662E-03	1.590E+00
1.100E+02	1.642E+00	9.798E-02	7.433E-03	0.000E+00	3.855E-02	3.205E-02	1.476E-03	1.819E+00
1.200E+02	1.849E+00	1.029E-01	8.025E-03	0.000E+00	4.112E-02	3.215E-02	1.332E-03	2.034E+00
1.300E+02	2.047E+00	1.074E-01	8.663E-03	0.000E+00	4.865E-02	3.305E-02	1.222E-03	2.246E+00
1.400E+02	2.239E+00	1.107E-01	9.313E-03	0.000E+00	5.825E-02	3.457E-02	1.125E-03	2.453E+00
1.500E+02	2.409E+00	1.126E-01	1.014E-02	0.000E+00	6.584E-02	3.619E-02	1.055E-03	2.635E+00

$n + {}^{206}\text{Pb}$ nonelastic and production cross sections



$n + {}^{206}\text{Pb}$ angle-integrated emission spectra



scattering and reaction cross section data for Ni-58, we have employed the following combination of proton potentials:

0 to 5 MeV : Harper potential (Ha82b)
6 to 47 MeV : Koning and Delaroche (Ko97)
48 to 260 MeV : Present OMP

For deuterons, the Lohr-Haeberli (Lo74) global potential was used; for alpha particles the McFadden-Satchler (Mc66) potential was used; and for tritons the Becchetti-Greenlees (Be71) potential was used. The He-3 channel was ignored.

The direct collective inelastic scattering to the following level in Ni-60 was considered by the DWBA-mode calculation of ECIS95 (Ra96) :

Jpi Ex(MeV) Deformation length
2+ 1.331 0.8535

The deformation length was determined to much the ENDF/B-VI value at 20 MeV.

Certain nuclear level densities were modified from the default values in accordance with experimental level-density information as follows. The level density of 57Fe was matched to the observed D-0 value by modifying the pairing energy to 0.15 MeV; the level density of the main competition channel, neutron emission to 60Ni, was adjusted to match Fischer et al.'s (Fi86) value of 3.85e3+-25% at 11 MeV excitation energy, but then increased slightly (a total density increase of 11%) by using a pairing energy of 1.1 MeV, since Haight's alpha production at 14 MeV is approx. 11% smaller than Fischer et al.'s measurements. Production of residual nuclei 59Ni and 56Fe, through (n,2n) and (n,na) reactions, become particularly important above 14 MeV. Pairing energies were adjusted to match the level density for 59Ni at the neutron binding energy (D0=12.9 keV), and Fischer et al.'s result for the 56Fe level density at 11 MeV.

The new Haight et al. (Ha97) LANL/WNR 60Ni(n,x alpha) data up to 50 MeV was used to benchmark our model calculations (Ch97) - agreement with experiment was good.

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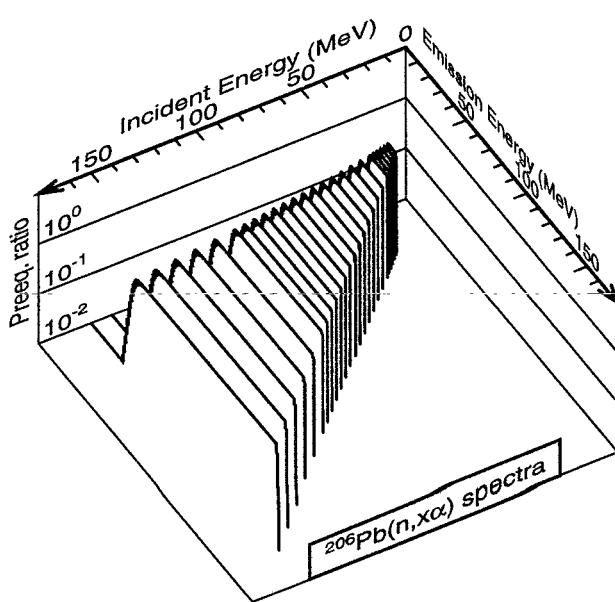
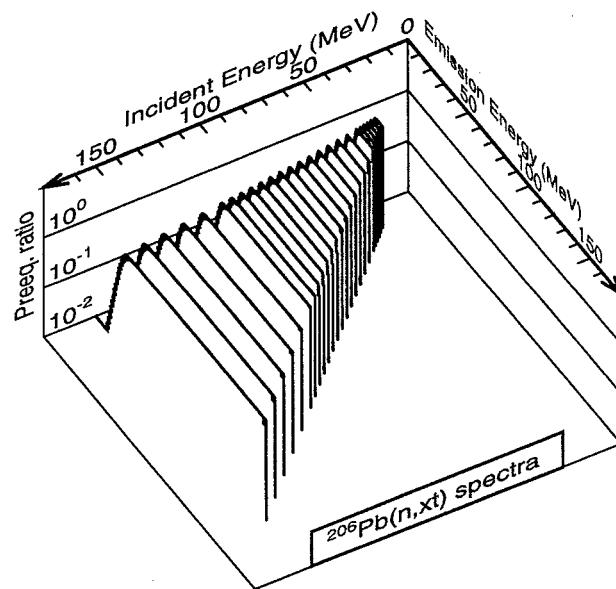
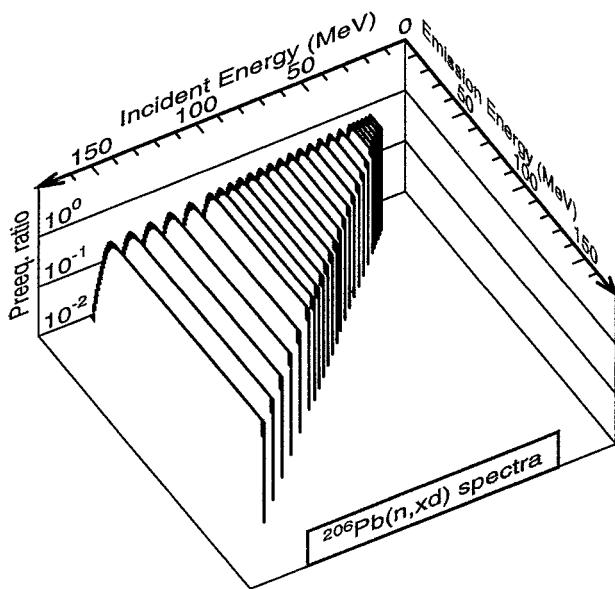
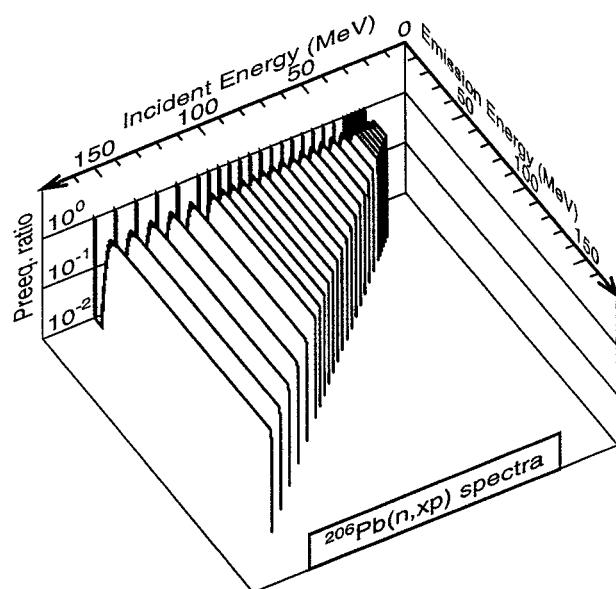
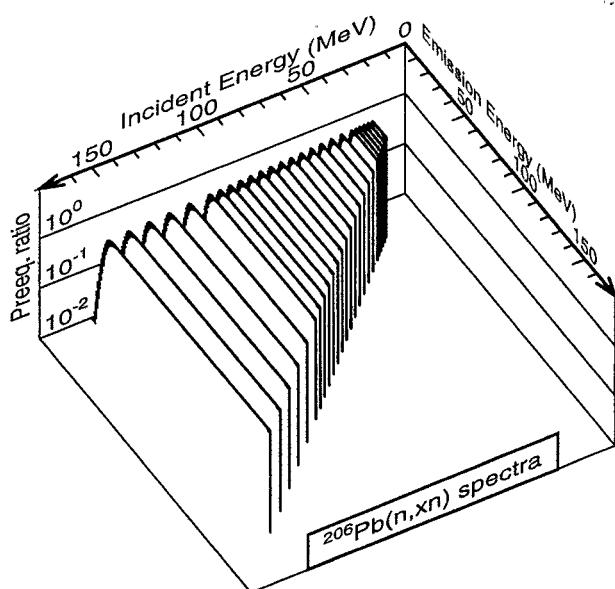
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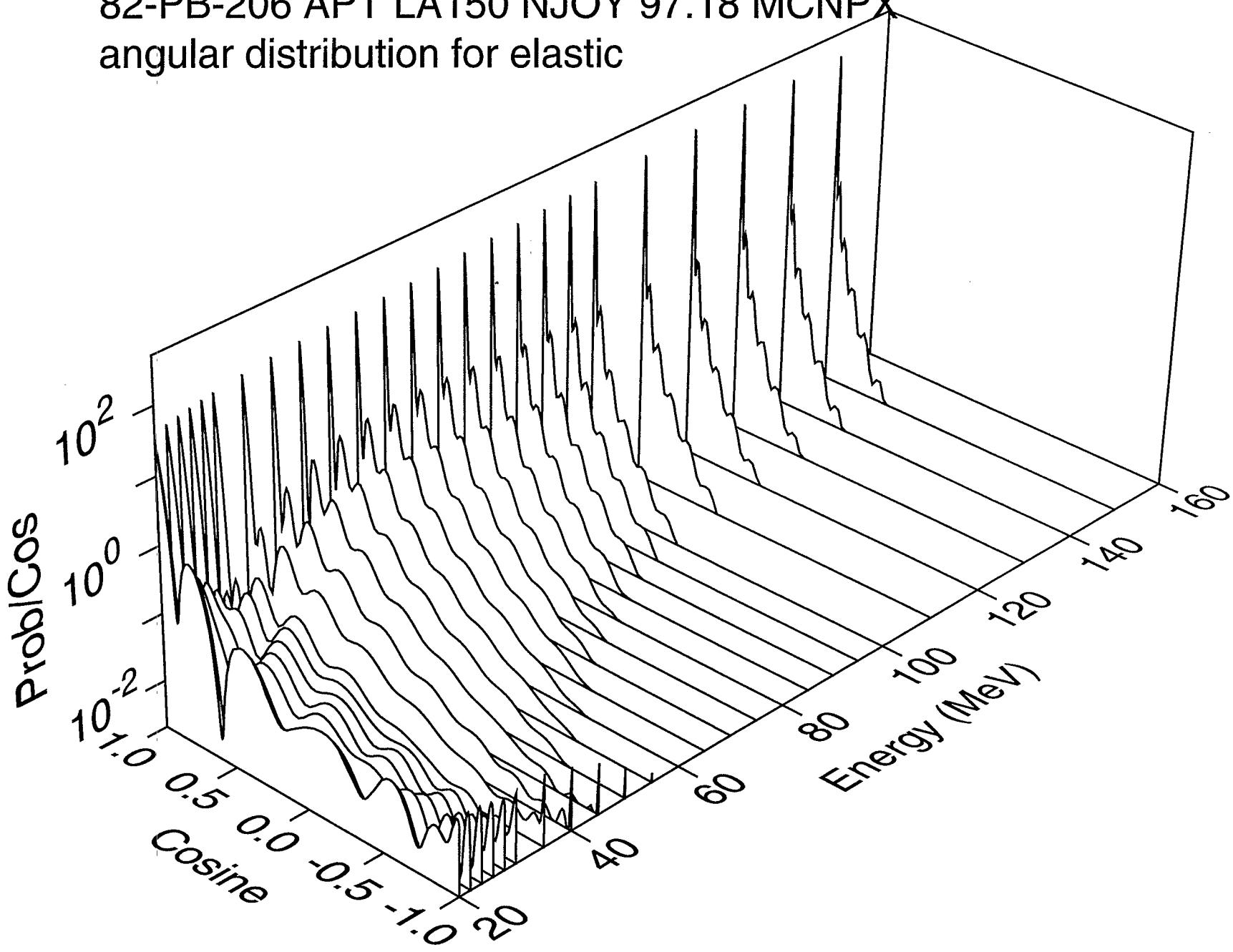
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$n + {}^{206}\text{Pb}$ Kalbach preequilibrium ratios

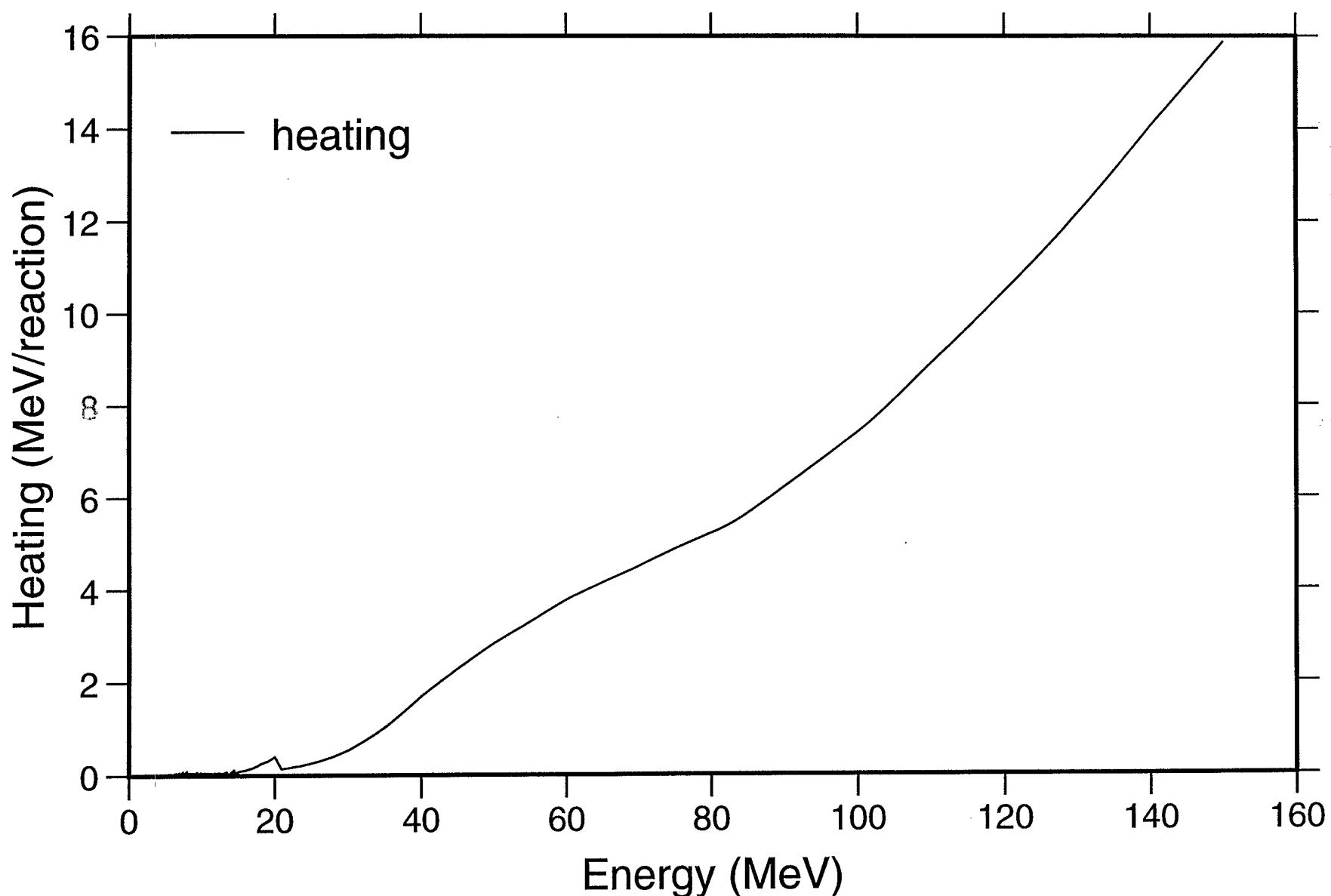


82-PB-206 APT LA150 NJOY 97.18 MCNPX
angular distribution for elastic



82-PB-206 APT LA150 NJOY 97.18 MCNPX

Heating



82-PB-206 APT LA150 NJOY 97.18 MCNPX
Damage

